Progress in NASA Rotorcraft Propulsion

By

Dr. Christopher DellaCorte
NASA Glenn Research Center

Abstract:
This presentation reviews recent progress made under NASA's Subsonic Rotary Wing (SRW) propulsion research activities. Advances in engines, drive systems and optimized propulsion systems are discussed. Progress in wide operability compressors, modeling of variable geometry turbine performance, foil gas bearings and multi-speed transmissions are presented.

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Christopher DellaCorte

Associate Principal Investigator (API)

Susan M. Johnson

Associate Project Manager (APM)

SRW Propulsion: Background (Motherhood)

- Rotorcraft propulsion is a critical element of the overall aircraft.
- Rotor/propulsion system is used for aircraft lift and forward flight and maneuvering.
- Rotorcraft engine/gearbox system must be highly reliable and efficient.
- Trends call for more versatile and efficient and powerful aircraft challenging propulsion system technologies.
- Advanced tools and methodologies must be developed to design new engine and drive systems.

SRW Propulsion-Tasks & POC's

Engine/drive system focus areas/main research tasks

- Variable Multi-Speed Drive System
- Improved Drive System Analytical Tools
  - Dr. Robert Handschuh
- Optimized Propulsion System
- Oil-Free Engine Technology
  - Dr. Robert Bruckner
- Wide Operability Engine Technology
  - Dr. Michael Hathaway
- Efficient, High Power Density Engine Technologies.
  - Joseph Veres

Subsonic Rotary Wing Project
1.0 Propulsion
FY 08 Plan

 3/6/08

WBS	TASK	Milestones (2007 – 2013)
1.1.1	Variable Multi-Speed Drive System	Variable Speed Dr Cncpt & Models 9/07; Propulsion/Rtr Systm Mdl Dev Compl 9/08; Lumped Mass Dyn Mdls Dev to Eval Speed/Changes 9/09; Validate Variable/Multi Speed Technologies/Concpts 9/11
1.1.2	Improved Drive System Analytical Tools	Tech Rpt Assessing Current Gear Windage vs Exisiting Data 9/07; Gear Windage Prediction Model Validated 3/09, 9/09; Improv'd Probabilistic Methodlogy Val'td Gear Bending/Surface Fatigue 9/10; Improved Drive Lube Model/Concepts 9/11
1.1.3	Optimized Propulsion System	Tech Rpt Assessing Predictive Mdl Capabil vs Cncpts/Exist'g Data 9/07; Systm Lev Benifits Assmt/Eng-Gearbox; Engine / Gearbox Integ Model 9/09; Optimized Engine/Gearbox Integration Studies 9/10; Gear Damage Life Ptedict'n Mdls 9/10; Validated Optimized Eng/Gearbox Cncpt Demo in Lab Envir 9/11
1.1.4	Oil Free Engine Technology	Foil Bearing Tool Capabil; Assess Oil Free 9/08; Tech Rpt Assessing Foil Bearing Capabil 6/08; Database/Valid'tn Physics Based Mdl 6/09; Predictive Mdl for Oil Free Engine Core 9/10; Database for Validation of Physics-Based Propulsion Systm 9/11
1.2.1	Wide Operability Engine Technology	Assess SOA Tools/Cncpts; Tech Rpt Assessing Predict Capabil 9/07; Validated Tool for Modeling 1 Stall Control Concept 9/08; Dev Optimum Eng Flow Cntrol for Wide Operability 9/09; Dev Cooling & Secondary Flow Optim Methodology 9/10; Des Guidelines/1 Flow Cntrl Concept Wide Operabil Eng Op 9/11
1.2.2	Efficient High Power Density Engine Technologies	Assess SOA Tools/Cncpts; Tech Rpt Assessing Predict Capabil 9/07; Valdiated Capability/ Des of Highly Ld Compressors 9/09; Demo Highly Ld Turbo Systms 6/11; Des Guidelines for 1 FLow Cntrol Cncpt for Increased Stage Static Pressure Rise Capabil 9/11

Lots of milestones and reports to track progress

SRW Propulsion-Primary Facilities

- <u>Research Facilities*</u>
  - <u>Mechanical Components</u>
    - Existing gear and transmission test cells
    - Gear windage rig and variable speed drive rig in build-up
  - <u>Tribology</u>
    - Foil bearing and tribology test rigs, Capstone turbine engine, coating development and manufacturing facilities
    - Surface analysis and metrology capabilities
  - <u>Turbomachinery</u>
    - Engine testing capability: current work using modified T700 with stall control technology and variable vane scheduling
    - Compressor test capability: upgrades to CE-18 facility, data collection and test article development collaborations with industry

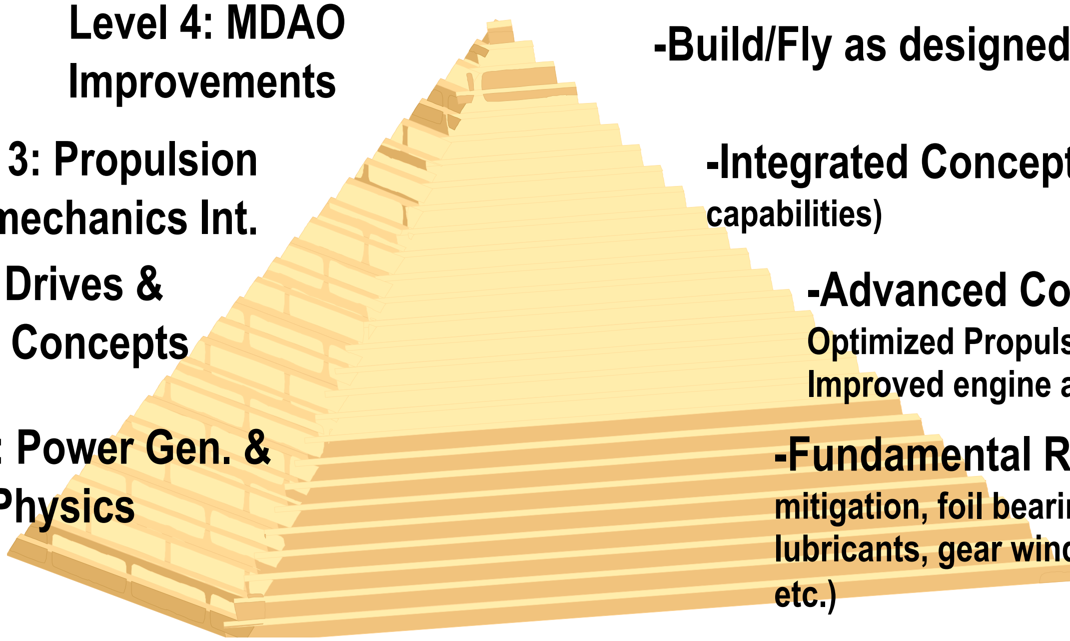
**At GRC, supported by facilities, engineering design and research technical support divisions.*

SRW Propulsion-NRA Collaborations

- **Transmissions/Drives**
  - High Fidelity CFD Analysis and Validation of Rotorcraft Gear Box Aerodynamics Under Operational and Oil-Out Conditions-Penn State- PI: R. Kunz
  - Comprehensive Modeling and Analysis of rotorcraft Variable Speed Propulsion System with Coupled Engine/Transmission Rotor Dynamics-Penn State-PI: E. Smith/K. Wang
- **Oil-Free Technology**
  - Prediction of Foil Bearing Performance: A Computational Model Anchored to Test Data: Texas A&M-PI: L. San Andres
- **Engines**
  - Advanced compressors-NRA award in process

**At GRC, supported by facilities, engineering design and research technical support divisions.*

SRW Propulsion: Project Levels Pyramid



Level 4: MDAO Improvements — **-Build/Fly as designed,** (enhanced fidelity, ~2x better every 5 yrs)

Level 3: Propulsion Aeromechanics Int. — **-Integrated Concepts,** (engines & drives for slowed rotor capabilities)

Level 2: Drives & Engines Concepts — **-Advanced Components,** (Variable Speed Drives, Optimized Propulsion, Wide Operability Aero components, Improved engine and drives models, Oil-Free engine bearings)

Level 1: Power Gen. & Trans. Physics — **-Fundamental Research,** (drive models, engine stall mitigation, foil bearing modeling, tribological coatings and lubricants, gear windage, compressor research, rotordynamics, etc.)

As technologies mature, they climb pyramid towards integration and deployment

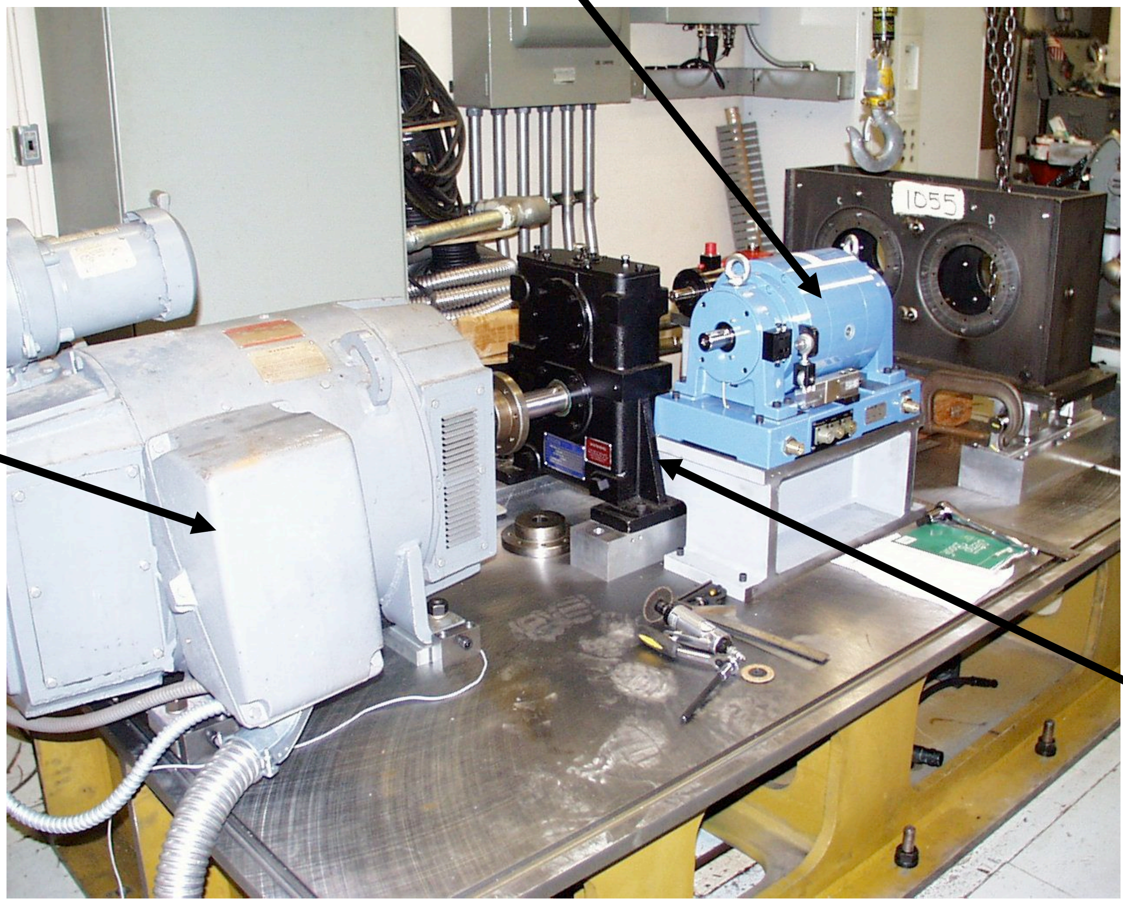
Drives: Gear Windage Test Facility at NASA-GRC

(Under Development)

Magnetic Loader

Test Gearbox

Drive Motor



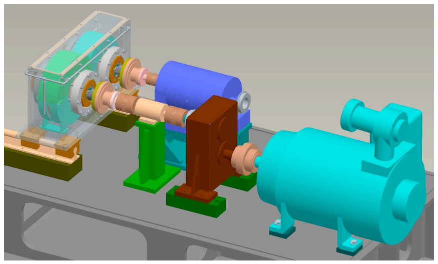
Speed Increasing Gearbox

Dr. Robert F. Handschuh, Army Research Lab, NASA - Glenn

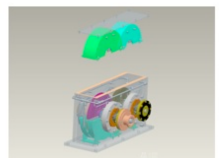
Mark A. Stevens, NASA Glenn Research Center

Penn State Gearbox CFD NRA: CFD Simulations Contribute to Design of NASA Test Rig

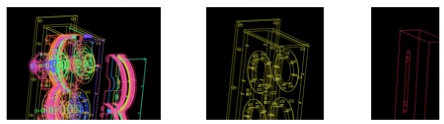
NASA Windage Rig Concept

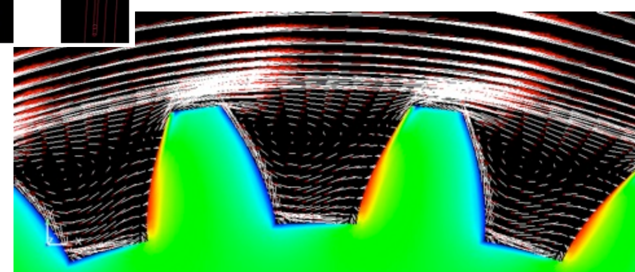


Penn State Rendering enables flow analysis



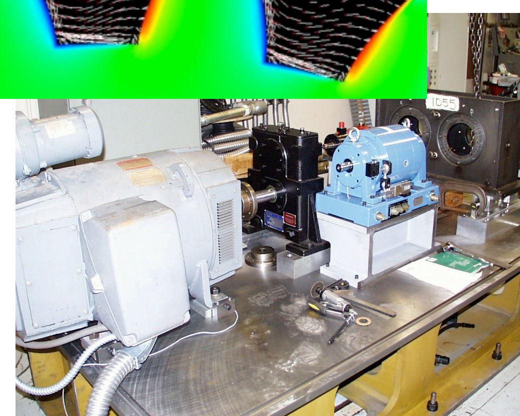
Preliminary Penn State CFD flows help guide rig detailed design





Close collaboration between SRW researchers and NRA PI provides mutally beneficial reults

Windage Rig (2008)

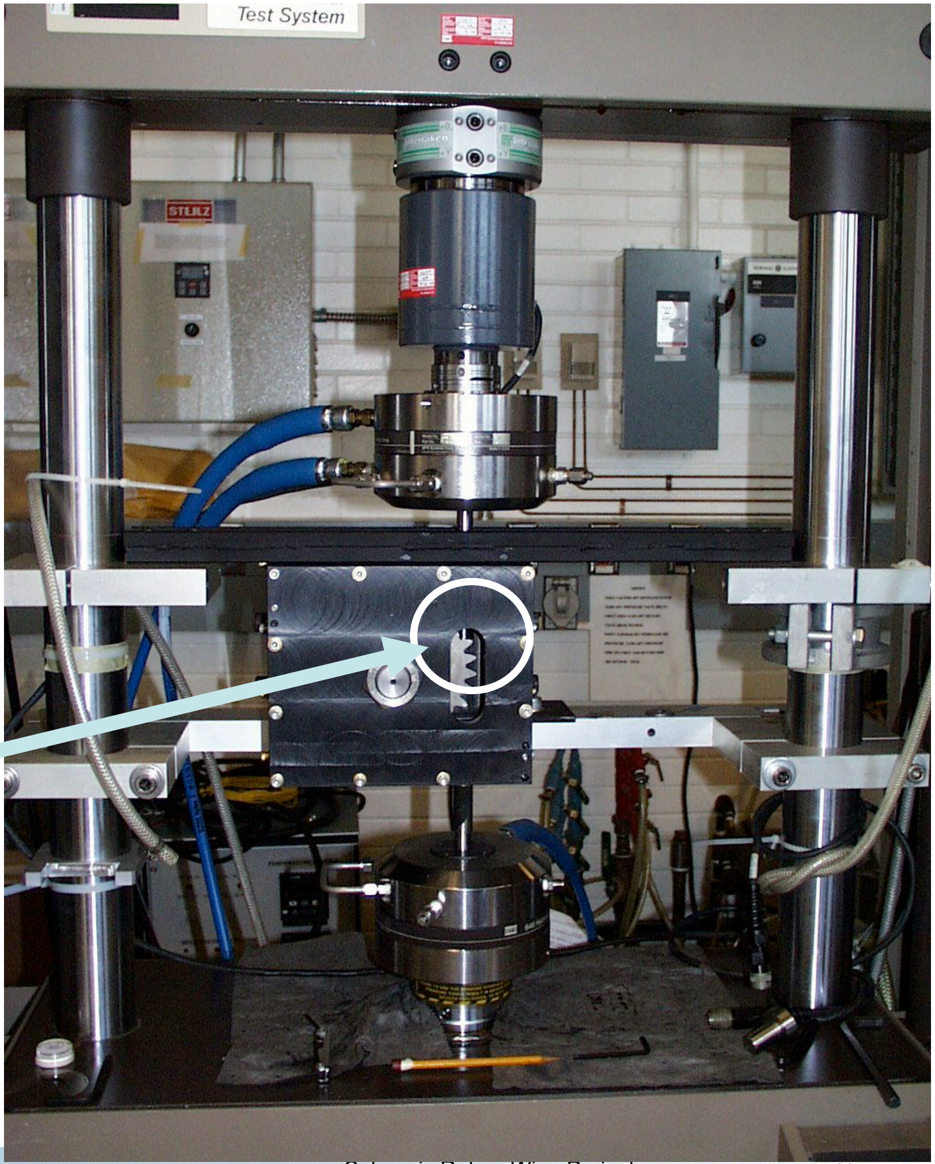


NRA COTR-Dr. Robert F. Handschuh, US ARMY/NASA – Glenn
NRA PI-Dr. Roger Kunz, Penn State University-ARL

Drives-GRC Gear Fatigue Test Stand

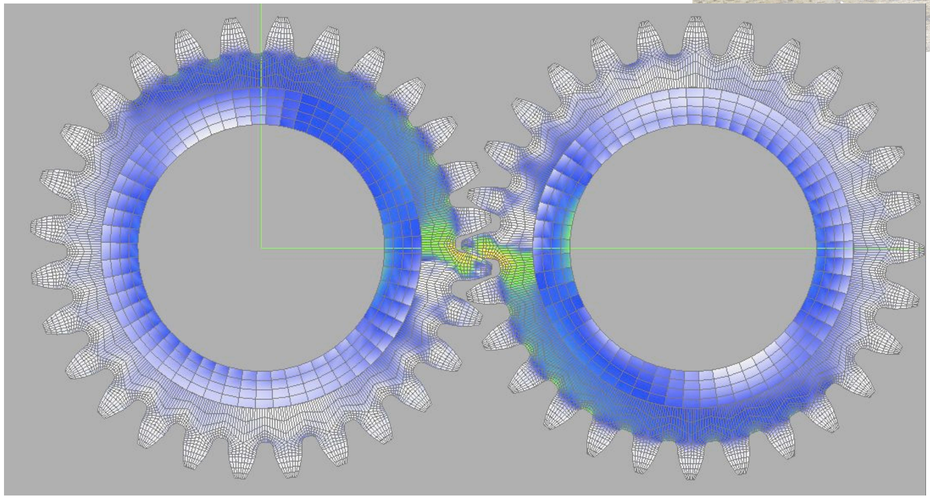
- Gear tooth bending fatigue
- Effects of surface finish
- Effects of laser peening

Test specimens:
Plunger on tooth

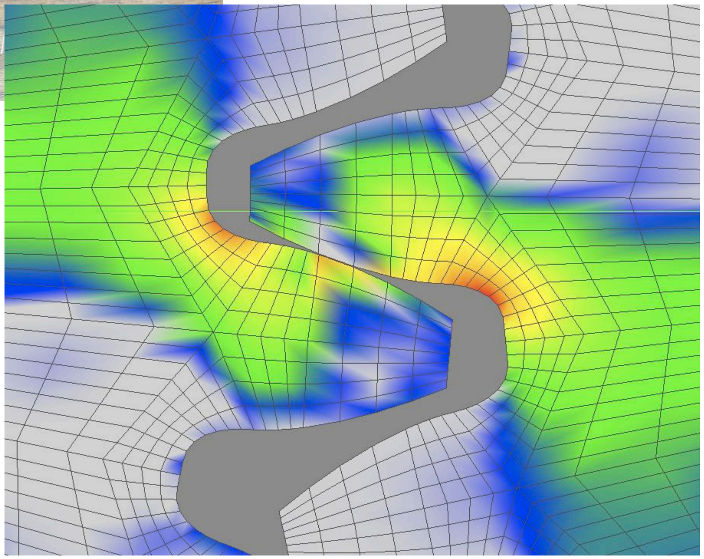


Laser Shot Peening: Modeling vs. Experimental Component Testing

Test Gears (Multiple teeth sectors on each gear allow for repeats)



FE Model of test gear set



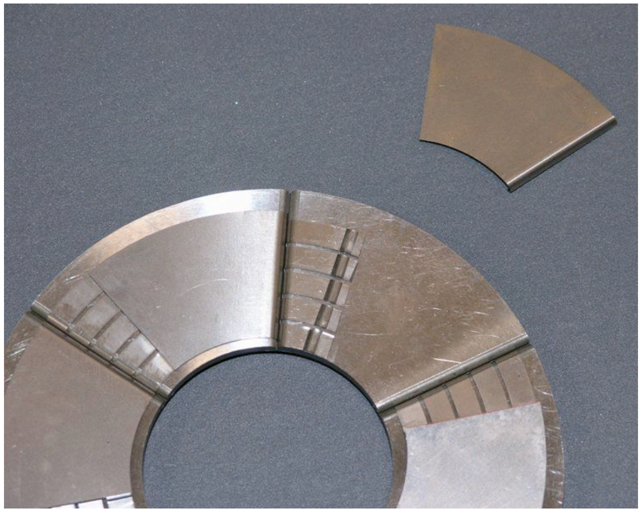
FE contact stresses

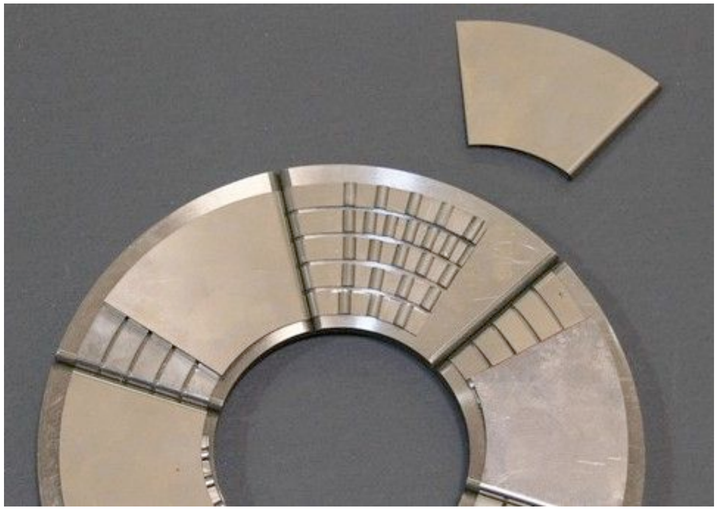
SRW Propulsion- Oil-Free Engine Technology/ Optimized Propulsion System (R. Bruckner)

- **Oil-Free Engine Technology**
  - **Develop foil gas bearing technologies**
    - **Manufacturing ,solid lubes, predictive tools and experimental tests**
  - **Demonstrate oil-free engine rotor systems**
    - **System integration tools, rotor experiments**
- **Optimized Propulsion Concept**
  - **Oil-Free engine utilizing S-O-A foil gas bearings**
  - **Highly loaded gearbox using gear specific high viscosity oil**
  - **System level studies underway to capture benefits and identify challenges**

SRW Propulsion-Oil-Free Engine Technology

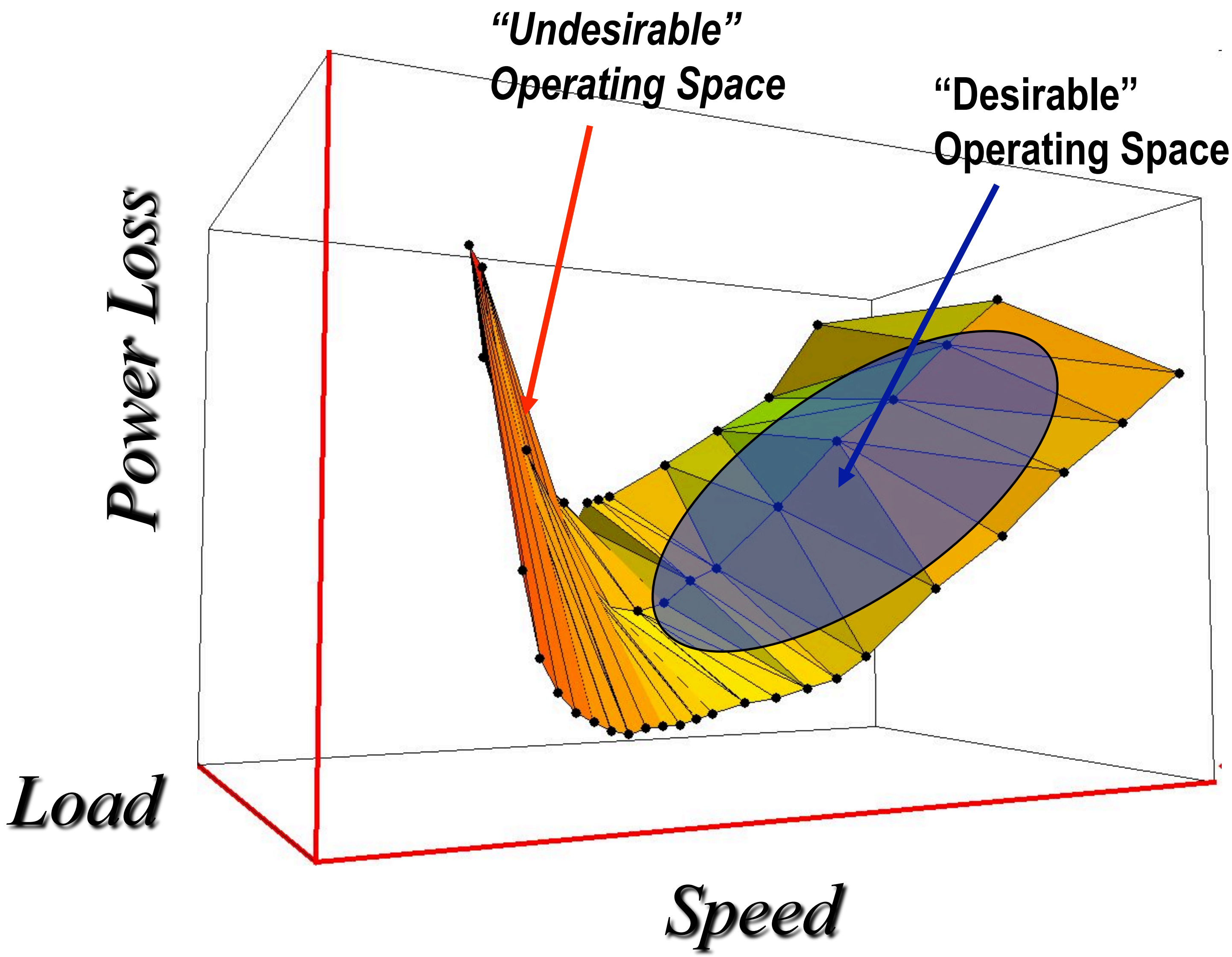
- Open source bearing fabrication
- Provide bearings for code validation database development
- Bring new suppliers to market for engine company support



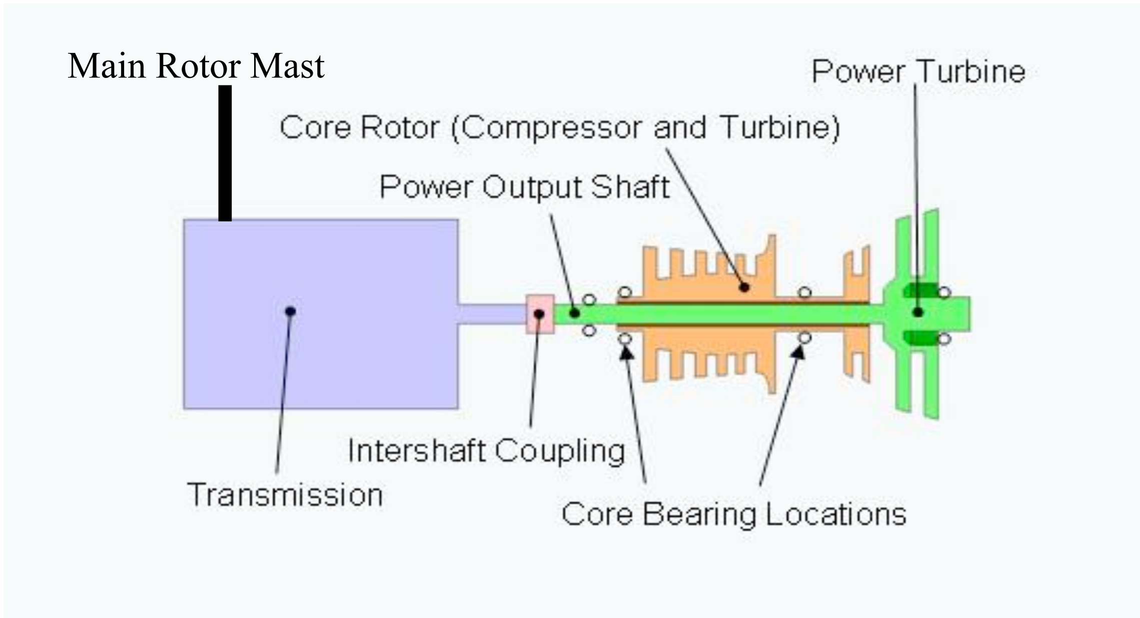


Research thrust foil bearings designed for convenient disassembly, instrumentation and ease of manufacture.

SRW Propulsion-Oil-Free Engine Technology



SRW Propulsion-Optimized Propulsion System



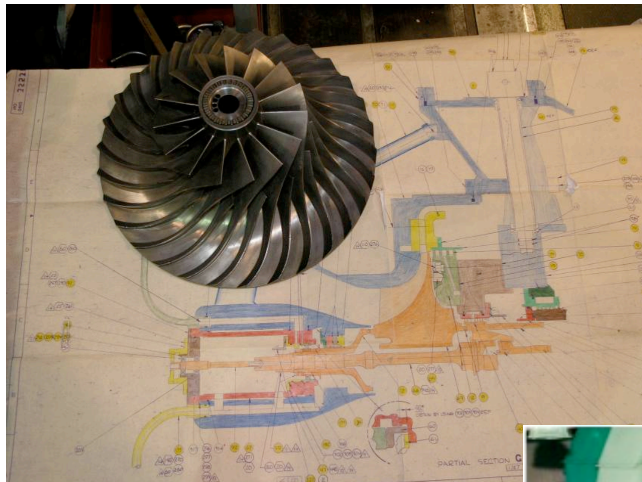
- Oil-Free engine-foil bearings enable higher speed, lower weight
- High power density transmission using high viscosity gear oil

SRW Propulsion-Power Generation Physics

- **Experimental Activities**
  - T700 Active Stall Control Engine Characterization
    - Conducting compressor guide vane scheduling tests
    - Planned blade deflection (light probe) measurement system
  - CE-18 Compressor Facility
    - Re-certification on track for early 2009 restart
    - Calibration existing CC3 compressor
    - Finalizing NRA for advanced compressor research
    - Open to collaborative test projects
- **Propulsion Modeling**
    - Initiated notional design for large civil tilt-rotor class engine
    - ROM 1-D component design (compressor)

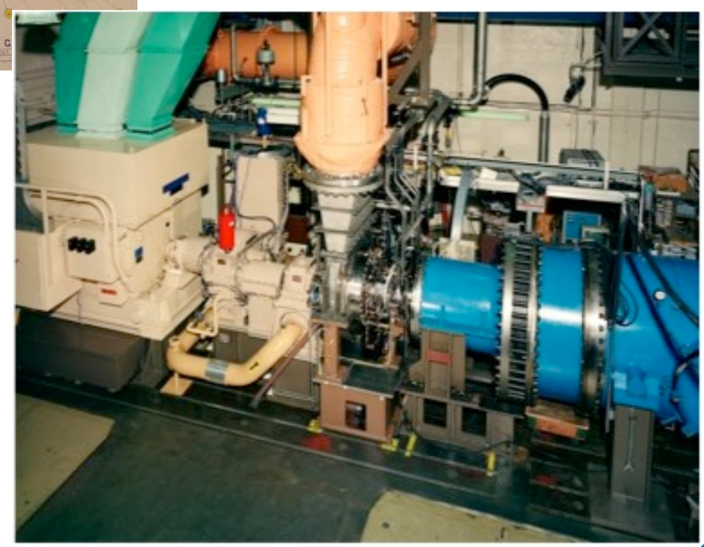
NRA: Advanced Compressor design-build

Based upon CC3 compressor hardware



Close collaboration between SRW researchers and NRA PI will provide mutually beneficial results

First research use for CE-18 in many years.

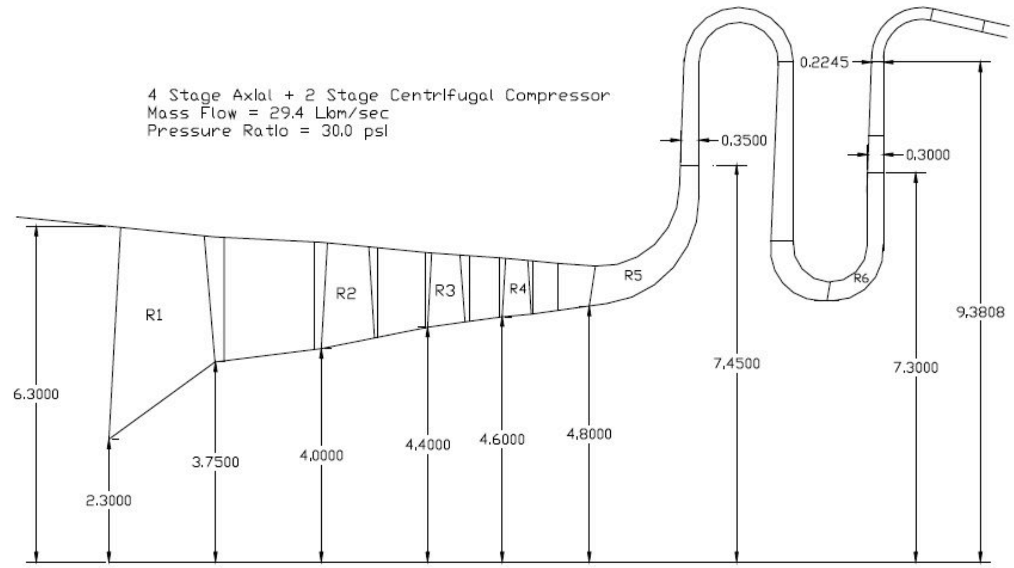


NRA COTRs-J. Welch and E. Braunscheidel

NRA: Pending

SRW Propulsion-Power Generation Physics

- Conceptual Design study of a compressor for a notional Large Civil Tilt Rotor Engine (LCTR2)
- 30:1 pressure ratio at a flow rate of 28 lbm/sec.
- Two main configurations: eight stage and an axi-centrifugal compressor (four axial and two centrifugal stages)
- Preliminary designs appear reasonable



Stage >	1 Axial	2 Axial	3 Axial	4 Axial	5 Centrifugal	6 Centrifugal
Mach Abs Inlet	.53	.47	.47	.40	.47	.47
Rel Mach Tip	1.50	1.26	1.12	1.00	0.88	0.84
Press Ratio	2.11	1.69	1.50	1.39	2.60	1.60
Blade Angle LE	63.1	65.0	63.1	64.5	54.4	54.5
Blade Angle TE	43.0	51.6	48.3	50.0	30.0	32.2
Solidity Tip	1.74	1.54	1.43	1.36	1.27	1.27
Blade Number	23	36	46	56	24	24
Exit Temp (R)	660	783	893	993	1361	1588
Tip Speed	1500	1452	1360	1300	1845	1571
Power (HP)	1420	1230	1107	1007	3758	2411

SRW Propulsion-Summary

- **Progress:**
  - Investments in facilities and capabilities
  - Strong team developed
  - Good balance of analytical and experimental effort
  - Stable agency level support

- **Opportunities:**
  - Several technologies ready for system level 3 insertion.
  - Test-beds can support industry efforts.
  - Processes in place for collaborations (NRA, SAA, etc.)